

# Three-Dimensional Modeling of Sediment Trapping and Dispersal on River-Influenced Continental Shelves

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## LONG-TERM GOALS

The goal of this project is to quantify processes that transport sediment in the coastal ocean and subsequently modify the seabed using a combination of numerical and observational techniques. We can use a numerical model that accounts for several processes that transport sediment to compare their relative contributions to transport, and modifications of the seabed.

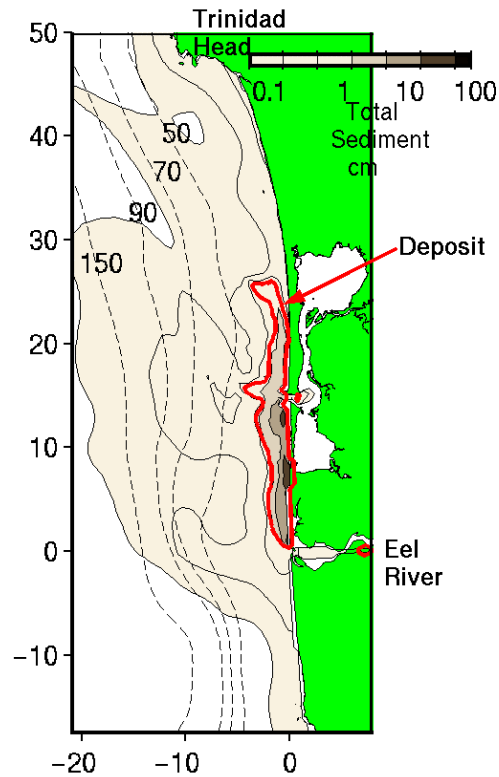
## OBJECTIVES

Many of the processes that transport sediment in coastal seas (wave/current resuspension, wind-, tidal-, and buoyancy-forced currents) are included in a three-dimensional, numerical model that has been applied to the Eel River shelf, northern California (Harris, Geyer and Signell, 2000). This accurately estimates the volume of sediment deposited on the shelf by floods of the Eel River, but predicts deposition on the inner shelf (Figure 1), which is contrary to observations that flood deposition is concentrated off-shore of the 50m isobath (Wheatcroft, *et al.*, 1997). Evidence from the Eel River shelf shows that sediment concentrations can become high enough ( $> 10$ 's g/L) in the near-bed region to induce down-slope transport driven by the weight of the suspension (Ogston, *et al.*, 2000; Traykovski, *et al.*, 2000). To account for sediment dispersal on energetic, depositional margins, it therefore appears necessary to consider gravity-driven transport of sediment as well as wave-current resuspension and plume processes. Dense near-bed layers were not represented in the calculations shown in Figure 1, and most models that do include them neglect either the three-dimensionality of the system, or transport processes above the wave-boundary layer (see, e.g. Scully, *et al.*, in review, 2002). We have incorporated gravitationally-forced transport of a dense near-bed layer into a three-dimensional sediment transport model of the Eel River shelf so that we can compare the relative contributions of this mechanism with wave/current resuspension and plume processes and evaluate whether these three processes can explain observed shelf deposition.

## APPROACH

Near-bed observations by Traykovski, *et al.* (2000) indicate that the sediment-laden layer scales in thickness with the wave-boundary layer ( $\sim 5$ -10 cm). In collaboration with Rocky Geyer and Peter Traykovski (both at Woods Hole Oceanographic Institution), I therefore added a wave-boundary layer component to the coupled three-dimensional hydrodynamic and sediment transport model, ECOM-SED (see Blumberg and Mellor, 1987).

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**Figure 1: Calculations representing a large flood of the Eel River, northern California in January, 1997. The amount of deposited and suspended sediment predicted 5 days after peak flood. Thickness of total sediment load (suspended and deposited) contoured in brown. Footprint of sediment deposit (>1 cm thick) shown as red line. Predicted volume of deposit agrees with observations, but location does not. (Length scale shown as x- and y-axis in km.)**

The conceptual framework developed in Traykovski's one-dimensional model is the basis for the new component of the three-dimensional model. It predicts suspended sediment concentrations and fluxes within a sediment-laden layer of the same thickness as the wave boundary layer, and was motivated by observations of a sharp density interface that often appeared at the top of the wave boundary layer. Sediment concentrations within the wave boundary layer were ~10's g/L, much higher than concentrations of overlying waters, ~1 g/L (Traykovski, *et al.*, 2000). At concentrations > 10g/L, the weight of a suspension can induce significant down-slope directed transport. Traykovski's one-dimensional formulation assumes suspended sediment profiles for the wave boundary layer and near-bed region, and an exchange between the two water layers that scales with the Richardson number at the density interface.

This formulation has been implemented within ECOM-SED by adding a wave-boundary layer at the base of the vertical grid of the three-dimensional model, and modifying Traykovski's representation of the wave-boundary layer to include sediment advection and limitations on bed sediment availability. The thickness of the near-bed turbid layer is equal to the wave-boundary layer thickness, and therefore is highest in the shallowest sites, and decreases offshore. Suspended sediment concentrations and horizontal velocities are predicted for this layer separately from the sediment routines normally included in ECOM-SED. As such, the wave boundary layer component replaces the bottom boundary

condition that is imposed in ECOM-SED's sediment transport routines. Sediment is exchanged between the wave boundary layer and the seabed, the overlying water column, and adjacent wave boundary layer grid cells. The sediment exchange rate within the seabed is found following Harris and Wiberg (2001) and is set to be the difference between the deposition rate (settling velocity  $\times$  concentration), and an entrainment rate equal to the product of settling velocity and Smith and McLean's (1977) reference concentration. Sediment concentration within the wave boundary layer is obtained through a mass-balance that includes horizontal fluxes, sediment flux from the bed, entrainment into, and settling out of the overlying water. The velocity of the sediment/water mixture within the wave boundary layer depends on a balance between the density anomaly of the suspension, and frictional drags between the wave boundary layer, the sea-bed, and the overlying water. Horizontal advection of sediment is implemented using an upwind advection scheme.

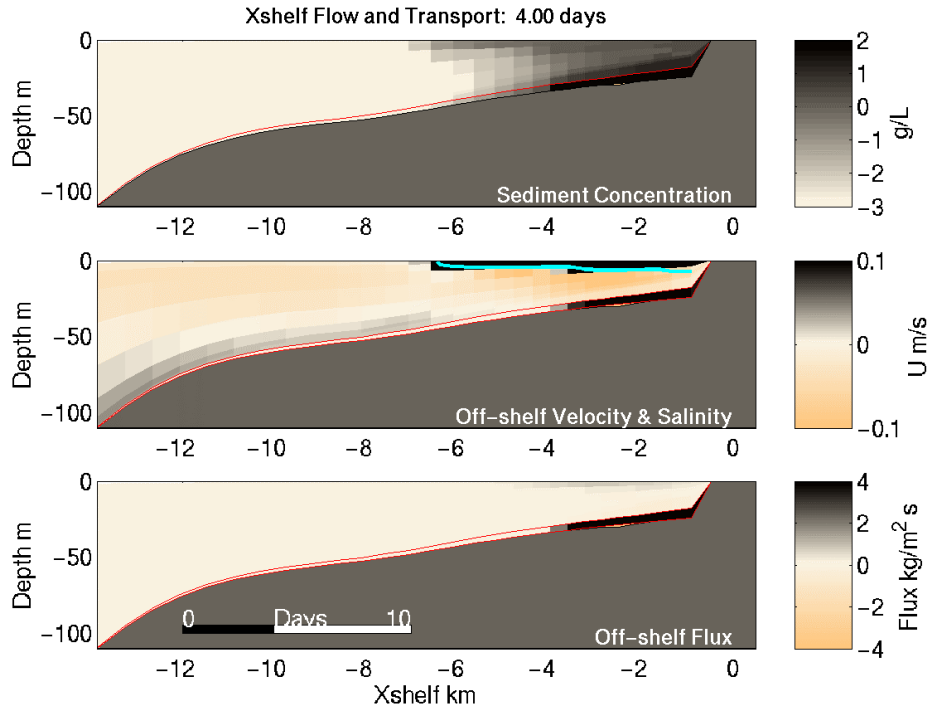
## WORK COMPLETED

A wave boundary layer grid was added underneath ECOM-SED's sigma coordinate grid system. The velocities and suspended sediment concentration predicted within this layer are similar to those predicted by Traykovski's one-dimensional model. The model was been implemented for a "sediment reworking case" that examines the ability of gravity-driven flows to drive cross-shelf transport, an "inner-shelf mobilization" case that predicts the ability of wave boundary layer transport to remobilize fine-grained sediment deposited in an inner-shelf environment, and a case modeled after a large flood of the Eel River that occurred in January, 1997. Studies of the sensitivity of calculations to wave and settling properties were presented in Harris, *et al.*, (2002).

## RESULTS

Resuspension of fine-grained sediment by energetic waves creates a dense layer of suspended sediment within the wave boundary layer that can significantly increase cross-shelf transport (Figure 2). The model was run for a case where flocculated and unflocculated fine grained sediment ( $w_s = 1.0$  mm/s and 0.1 mm/s, respectively) were delivered to the Eel River shelf at rates modeled after the January, 1997 flood event. Sediment concentrations are predicted to be very high, particularly in the inner shelf, and velocities of the wave boundary layer are on the order of 10's of cm/s (Figure 2). The wave-boundary layer velocities calculated for the inner- to mid-shelf region are much higher than the wind-driven cross-shelf currents, as are sediment fluxes, and velocities within the turbid layer at times flow off-shelf while overlying currents flow shoreward (Figure 2). The flux predicted within the wave boundary layer for these conditions delivers a 10—20 cm thick flood layer to the mid-shelf within a week of peak flooding (Figure 3). Nearly all of the sediment that reaches the near-bed turbid layers was delivered to the shelf as flocculated material, the unflocculated material is dispersed throughout the Eel River shelf and neighboring environments. To illustrate, nearly all of the sediment remaining in suspension at the end of the 10-day simulation is flocculated (Figure 3; right-most panel), whereas all of the flocculated material is confined to the seabed and near-bed turbid layer (Figure 3, left and middle panels, respectively). Animation of both Figures 2 and 3 were presented in Harris, *et al.*, (2002), and are available at [www.vims.edu/~ckharris/STRATAFORM.html](http://www.vims.edu/~ckharris/STRATAFORM.html).

Several processes impact settling characteristics within turbid layers, including aggregation / disaggregation and hindered settling, and we found the location of the mid-shelf flood deposit to be as sensitive to the manner within which we specified settling of sediment within the near-bed layer as it was to forcing parameters such as wave energy. The sensitivity of flood deposition to hindered settling



**Figure 2: Calculations for a transect located between Eel River mouth and Humboldt Bay, assuming sediment delivery, wind, and waves similar to the flood of January, 1997. Results shown at day 4 of a 10-day simulation. Top panel: sediment concentration. Middle panel: velocity of currents. Bottom panel: sediment flux. Values for wave boundary layer shown in layer near bed with thickness of wave boundary layer doubled. The blue line in the middle panel represents extent of buoyant plume.**

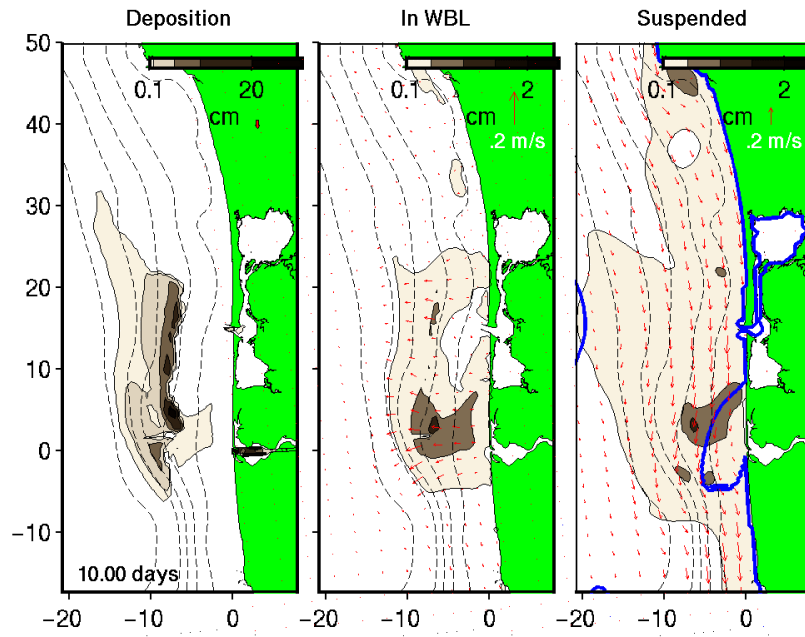
was tested using values for settling velocities as a function of concentration found in Mehta and McNally (2002). Decreased settling velocities within the near-bed turbid layer resulted in additional off-shelf transport of sediment, and the shoreward boundary of the flood deposit varied from 40m water depth to 90m water depth, using the range of hindered settling velocities found in the literature (Harris, *et al.*, 2002).

We conclude that the size and location of flood deposits are sensitive to sediment settling characteristics, both within the water column and within the near-bed turbid layer. Aggregation / disaggregation and hindered settling processes appear to impact initial flood deposition on the Eel River shelf as much as the wave energies and circulation present during flood events.

## IMPACT/APPLICATIONS

Further enhancement of this model promises to improve our ability to quantify sediment transport in coastal seas by better representing the near-bed flow and sediment fields that are critical to sediment transport. Additionally, gravitational forcing created by dense suspensions in the wave boundary layer appears to be a dominant cross-shelf transport mechanism in some environments. Further refinement of this numerical model will provide a tool for assessing the relative significance of this cross-shelf transport mechanism compared to wave-current resuspension and transport. The formulation was

completed within one subroutine that was added to ECOM-SED, and as such can be ported to other numerical models.



**Figure 3:** *Predicted deposition, amount of sediment in the wave boundary layer, and suspended sediment for case modeled on flood of January, 1997. Results shown at the end of a 10-day simulation. Red arrows in middle and right-most panels represent velocities in the near-bed wave boundary layer, and depth-averaged currents, respectively. Blue line in right-most panel represents extent of freshwater river plume.*

## TRANSITIONS

Our calculations of suspended sediment concentrations in the freshwater plume have been shared with other members of the STRATAFORM research team, and will be included in the forthcoming STRATAFORM master volume. We have additionally provided predictions of suspended sediment concentrations to Paul Hill (Dalhousie University). Results were presented to the scientific community at the 2002 Ocean Sciences Meeting (Harris, *et al.*, 2002).

## RELATED PROJECTS

I have continued to use a two-dimensional sediment transport model formulated for the continental shelf (previously funded by ONR's Geology and Geophysics Program, with contributions from the U.S. Geological Survey) to gain insight on the ability of wave-current suspension to modify the seabed. This resulted in the publication of a manuscript that examines feedbacks between sediment texture and transport on shelves (Harris and Wiberg, 2002), a manuscript that describes the model (Harris and Wiberg, 2001), and contributions to the STRATAFORM master volume.

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## **PUBLICATIONS**

Harris, C.K. and P.L. Wiberg (2001) A two-dimensional, time-dependent model of suspended sediment transport and bed reworking for continental shelves. *Computers and Geosciences*, 27 (6):675-690.

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